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Development of biofuels in South Africa: Challenges and opportunities

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ABSTRACT

Biofuels have a potential to extend and diversify South Africa's energy supply, thus reducing dependence on imported fuels and pollution levels. Despite several biofuel policies and mandates, biofuel development in South Africa has stalled in the legislative process and no large scale commercial biofuel project has materialized yet. Developing biofuels, especially using food grains, is a big challenge to the government of South Africa due to issues related to food security, commodity prices, economic and social concerns, and impacts of land use changes on the environment. The production cost of feedstock and employment creation opportunities from agricultural production play a vital role in selecting suitable feedstock for the region. Since considerable investment and infrastructure will be required for continued supply of feedstock and efficient biomass conversion technologies, rigorous research and comprehensive studies are required to identify feedstock and technologies best suited for the successful establishment of biofuel industry in South Africa.

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1. Introduction

Developing biofuels has many advantages, such as efficient utilization of renewable resources; enhanced energy security and energy supply diversification; enhanced rural agriculture development and investment in rural areas; reduced greenhouse gas (GHG) emissions; and increased jobs and improved livelihood. Global production of biofuels has been growing steadily from about 20 billion litres (125 million barrels) in 2001 to over 110 billion litres (692.5 million barrels) in 2011 [1]. During this period, worldwide production of ethanol and biodiesel has increased by almost five and twenty fold, respectively. The global biofuel production is projected to reach 222 billion litres by 2021, with ethanol and biodiesel share of 81% and 19%, respectively [2]. In 2011, biofuels provided around 3% of total fuel for road transportation worldwide [2,3] and it is projected to share 27% of world transport fuel by 2050 [3]. United States is a top producer of biofuels, followed by Brazil. The global contribution of South Africa in biofuel production is much less than 0.01% (Fig. 1).

Biofuels are fuels derived from biomass or waste feedstock. The most common biofuels are bioethanol and biodiesel. Bioethanol, or ethanol, is an alcohol made by fermenting sugar and starch components of crops (e.g. maize or sugarcane) using yeast and contains about 70% of the energy of fossil petrol [4]. Ethanol can be used as a fuel for vehicle in its pure form, but it is usually blended with petrol to increase octane number and improve vehicle emissions [5,6]. Cellulosic biomass, derived from non-food sources (such as straws, woody biomass and grasses), is also being developed as a second generation feedstock for ethanol production. Biodiesel is a fuel comprised of mono-alkyl esters of long chain fatty acids produced by reaction of triglycerides in vegetable oils or animal fats or waste oils with alcohol and contains about 91% to 94% of the energy of fossil diesel [4]. Biodiesel blends improve cetane number and vehicle emissions [7].

Several developed and developing countries have adopted mandatory biofuel policies and set biofuel targets (Table 1) to enhance energy security and contribute to climate change mitigation and rural agricultural development. Mandates and incentives for blending biofuels with fossil fuels contribute significantly to the on-going growth in biofuel production and use. Over the years, South Africa has also established several biofuel policies and mandates, such as Biofuels Industrial Strategy aiming to promote the production and use of biomass fuels, attract investment into

rural agricultural development, and create additional employment. Ethanol production in Thailand was estimated to generate 17–20 times more jobs than petrol production with agriculture contributing to more than 90% of the total employment [14]. The farming jobs created will depend on the feedstock and level of mechanization available for biofuel crops in the country [10]. For instance, jatropha will create most jobs as it is labour intensive, and the production of sugarcane in Brazil and maize in the United States is highly mechanized and will create fewer jobs. The estimates and potential employment from biofuel industry is presented in Table 2.

In recent years, several African nations (Table 1) have gone ahead with the decision to produce biofuel crops to slash fuel import volumes and bills. However in South Africa, biofuel development has stalled in a legislative process and biofuel is yet to be commercially produced in a large scale. The challenges hindering biofuel development in South Africa may include security to economic and social concerns, such as impacts on food security, commodity prices, biodiversity and environmental degradation due to land use changes. This paper explores the challenges behind the struggling biofuel industry in South Africa. The paper examines key reasons hindering biofuel development in South Africa, as well as the potential of establishing biofuel industry in the nation.

2. Drivers of biofuel expansion

The energy and economic crisis in the world has triggered the global interest on the development of biofuels as an alternative to fossil fuel [16,17]. Developing biofuels is desirable because they are derived from sustainable sources of energy [18] and considered to be carbon neutral [19]. The other drivers of biofuels include volatile fuel prices [16,17,20], utilization of agricultural surpluses [4,17,20], and creation of additional employment [4,20]. Non-OPEC countries with little or no fossil fuel reserves would benefit from the utilization of existing [16] and underutilized land resources.

The reduction of carbon and other emissions has been a major driver of biofuel expansion in the developed countries, whereas energy security, job creation, and rural social and economic development have been the major thrust for biofuel expansion in developing countries [21–23]. Several studies have been conducted on biofuel development in African countries and most of these studies suggest that African countries have a potential of producing biofuels for domestic and international markets [19,22,24,25]. Since Europe doesn't have sufficient agricultural land to produce enough biofuels to meet the EU target of 5.7% share of renewable fuel in transport and 10% by 2020, the European Union (EU) and other investors are interested in building biofuel production base in Africa [23,26].

Moreover, biofuels work in existing technology with little or no modification, mostly up to 10% blends for ethanol or even 100% for biodiesel [4]. Biofuels can be produced from a wide range of feedstock compared to crude oil which has limited alternative feedstock. There is a little scope of developing technological advancements for the already mature petroleum industry, whereas biofuel industry has a great scope for developing advanced and efficient technologies in future.

3. Importance of biofuels in South Africa

South Africa is the largest consumer of energy among Africa's 53 nations, accounting for about 31% of total primary energy

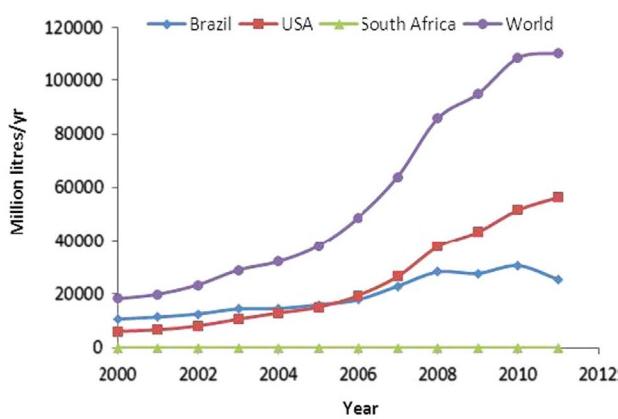


Fig. 1. Comparison of biofuel production [1].

Table 1

Biofuel policies and targets in selected countries and regions [2,3,8–13].

Country/region	Mandates or targets
Angola	• E10
Argentina	• E5 and B10 • B10 is mandatory for transport and thermal electric plants
Australia	• E4 and B2 (New South Wales) • E5 by 2017 and E10 by 2020 (nationwide)
Bolivia	• E10 and B2.5 • B20 by 2015
Brazil	• E20 and B5 • B10 by 2020
Canada	• E5–E8.5 and B2
China	• E10 (nine provinces) • E10 (nationwide) by 2020
Chile	• E5 and B5
Colombia	• E8–E10 and B10
Costa Rica	• E7 and B20
Ecuador	• B5
Ethiopia	• E5
European Union (EU)	• 5.7% share of renewable fuel in transport • 10% share of renewable fuel by 2020
Fiji	• Voluntary blends of E10 and B5
India	• E5 (E10 approved in Maharashtra) • E20 and B20 by 2017
Indonesia	• E3 and B2–B2.5 • E5 and B5 by 2015 • E15 and B20 by 2025
Jamaica	• E10
Kenya	• E10 (Kisumu city)
Malawi	• E10
Malaysia	• B5 • B7 (proposed)
Mexico	• E2 (Guadalajara) • E2 (proposed for Mexico city and Monterrey)
Mozambique	• E10 • B5 by 2015
Nigeria	• E10 and B20
Panama	• E2 • E5 (2014) • E7 (2015) • E10 (2016)
Philippines	• E10 and B2
Paraguay	• E24 and B1
Peru	• E7.8 and B2 • B5 (proposed)
South Africa	• E2–10 and B5 starting 2015
South Korea	• B2
Sudan	• E5
Taiwan	• B1 • E3 (proposed)
Thailand	• B5

Table 1 (continued)

Country/region	Mandates or targets
United States	• Ethanol production of 9 million litres per day from 2017 to 2022.
Uruguay	• 2014 volume in billion litres: cellulosic biofuel=6.6; biomass based diesel=3.8; advanced biofuel=14.2; and renewable fuel=68.7 (corn ethanol=54.5)
Vietnam	• GHG reduction: cellulosic biofuel=60%; biomass based diesel=50%; advanced biofuel=50%; and renewable fuel=20%
Zimbabwe	• B10 (Minnesota) • 136 billion litres of biofuels by 2022 of which 60 billion litres must come from cellulosic biofuels.

consumption in Africa in 2012 [27]. Transport sector is a large consumer of energy covering about one quarter of South African energy consumption. According to BP Statistical Review of World Energy 2013 [27], South Africa consumed an energy equivalent of 124 Mtoe in 2012, of which coal accounted for 72.5%, followed by oil (21.7%), natural gas (2.8%), nuclear (2.6%), and renewables (0.4%, primarily from hydropower). According to Energy Information Administration [1], South Africa contributed approximately 1.4% of global CO₂ emissions and was responsible for 40% of Africa's emissions in 2011, thus making South Africa to become the leading carbon dioxide (CO₂) emitter in Africa and the 14th largest worldwide. South African consumption of energy has increased CO₂ emission by 18% from 2001 to 2011.

South Africa has limited oil reserves and imports a significant amount of oil to meet the nation's oil requirements. South African proven oil reserves are about 2.4 billion litres (15 million barrels) and the total South African oil production was 28.8 million litres (181 000 bbl) per day at the end of 2012 [1]. With that rate of crude production and proven reserves, the reserves-to-production (R/P) ratio for South Africa is estimated to be 0.23 years. The R/P ratio is the number of years for which the current level of production of fuel can be sustained by its reserves and is calculated by dividing proven reserves at the end by the production in that year [28]. The 2012 estimate of total petroleum consumption in South Africa was 96.8 million litres (609 000 bbl) per day, of which approximately 68 million litres (428 000 bbl) per day was imported (70% of consumption). About 85% of petroleum fuel consumption in 2012 was covered by petrol (43%) and diesel (41%) [29].

South Africa needs alternative sources to cope with energy security and emission issues and save heavy foreign exchange spent on imported oil. Renewable fuels, such as biofuels, have the potential to extend and diversify South Africa's energy supply, which will help reduce South Africa's dependence on imported fuels and reduce carbon footprint. Biofuels can also help South Africa to achieve renewable energy goals, increase local energy access, uplift agricultural sector and its market, and boost economic and rural development of the country. Biomass energy (including liquid biofuels) along with wind, solar and small-scale hydropower are considered in the South African Policy on Renewable Energy, known as White Paper on Renewable Energy, as renewable sources to be exploited to produce a renewable energy target of 10 000 GW h by 2013 [30].

Table 2
Employment creation from biofuel industry [10,14,15].

Type of biofuel	Employment
Sugarcane production in Brazil and Mozambique	0.11–0.27 jobs/ha/year
Palm production in Malaysia and Indonesia	0.30–0.38 jobs/ha/year
Jatropha production in Indonesia	0.11–0.28 jobs/ha/year
Cassava production in Thailand and Mozambique	0.11–0.37 jobs/ha/year
Average ethanol plant	300 direct and additional 50% indirect jobs
Corn ethanol	1.1 jobs/million litres/year
Sugarcane ethanol	5.1 jobs/million litres/year
Palm oil biodiesel	73.3 jobs/million litres/year
Soybean oil biodiesel	3.5 jobs/million litres/year
Ethanol in APEC countries	45 000–175 000 jobs (1st generation) 2414 000 jobs (2nd generation estimate)
Biodiesel in APEC countries	197 000–651 000 jobs (1st generation)
Ethanol in Brazil	39 direct jobs/million litres/year
Biodiesel in Brazil	83.3 jobs/million litres/year
Ethanol in United States	4.2–4.4 jobs/million litres/year
Biodiesel in United States	13 jobs/million litres/year
Cassava ethanol in Thailand	117 jobs/million litres/year
Molasses ethanol in Thailand	112 jobs/million litres/year
Sugarcane ethanol in Thailand	121 jobs/million litres/year
Palm biodiesel in Thailand	128 jobs/million litres/year
Ethanol in Thailand in 2022	238 700–382 400 jobs

Table 3
Biofuel Plants on pipeline [34].

Name	Type (feedstock)	Capacity (million litres/year)	Location
Arengo 316P. Ltd.	Ethanol (sorghum)	90	Cradock, Eastern Cape
Mabef Fuels	Ethanol (sorghum)	158	Bothaville, Free State
Ubuhle Renewable Energy	Ethanol (sugarcane)	50	Jozinini, KZN
E10 Petroleum Africa CC	Ethanol	4.2	Gauteng, Germiston
Rainbow Nation Renewable Fuels Ltd.	Biodiesel (soybean)	288	Port Elizabeth, Eastern Cape
Phyto Energy	Biodiesel (canola)	> 500	Port Elizabeth, Eastern Cape
Exol Oil Refinery	Biodiesel (WVO)	12	Krugersdorp, Gauteng
Basfour 3528 P. Ltd.	Biodiesel (WVO)	50	Berlin, Eastern Cape

3.1. Status of biofuels in South Africa

South Africa's history of using biofuel dates back to the 1920s when sugar ethanol was blended with petrol [4,21]. The blending was halted in the early 1960s due to cheaper imported fossil fuels which made blending economically unviable. The potential of biofuels to fulfil energy and economic security has renewed the public and political interest on biofuels. The government of South Africa established Biofuels Industrial Strategy in 2007 to address the renewed interest on need of biofuels in the country.

Despite many policy statements and plans over the years, biofuel production in South Africa is still in its infancy [31] and very few small scale biofuel plants are available in the country [16]. Currently, there are about 200 small plants producing biodiesel, mostly using waste vegetable oil (WVO) as feedstock [32] which neither competes with food nor with agricultural land. The production rate of these plants is quite low because owners prefer batch reactors over continuous reactor due to low acquisition cost, simple design and ease of operation [33]. Ethanol, which is produced at small and medium scale, is mostly being used in non-fuel purpose (e.g. solvent, food and beverages, pharmaceuticals, etc.) and exported to EU market [4]. The 2011 estimate of the production of ethanol and biodiesel in South Africa was only about 16 000 and 4770 l per day, respectively [1]. However, few manufacturing sites have been identified and licenced for commercial biofuel production within South Africa (Table 3).

3.2. South African biofuel policy

In 2007, Biofuels Industrial Strategy was ratified by the South Africa government based on a feasibility study of the National Biofuels Task Team [35]. The strategy is aimed at achieving a number of goals, including attracting investment into rural areas, promoting agricultural development, poverty alleviation through sustainable income earning opportunities, and import substitution of foreign oil. The strategy had aimed to achieve 2% penetration of biofuels in the national liquid fuel supply by 2013, which is equivalent to 400 million litres per annum [17]. The strategy had estimated the creation of about 25 000 jobs in rural farming and contribution of up to 50% to the renewable energy target of 10 000 GW h by 2013 [36].

The strategy recommended sugarcane and sugar beet as feedstock for ethanol production; and sunflower, canola and soybeans for biodiesel production; however it has currently excluded maize and jatropha citing concerns related to food security, possible price hikes and environmental concerns. The strategy also briefs biofuel incentives—ethanol falls outside the fuel tax net, hence is 100% exempt from fuel tax; whereas biodiesel falls within the fuel tax net, hence biodiesel manufacturers receive a rebate of 50% on the general fuel levy.

The Biofuels Industrial Strategy focuses more on previously disadvantaged communities and emerging farmers. The strategy focuses on economic and social development of rural areas

through the agricultural development in the former homeland areas [21,37]. The South African government plans to place a quota that requires a minimum of 25% of the feedstock to be supplied by small scale farmers in achieving proposed biofuel blends.

In August 2012, the South African government revised regulations regarding the mandatory blending of biofuels with fossil fuels, allowing for 5% blending of biodiesel with diesel and a range of 2% up to 10% blending of ethanol with petrol [11]. With a blending target of 10%, about 125 000 direct jobs could be created mainly based in rural areas. According to the South African Department of Energy, the mandatory biofuel blending will commence from the first of October 2015. The effective date has been proposed considering the time needed to finalise the Biofuels Pricing Framework and to develop and install infrastructures required to manufacture, supply and blend biofuels [38].

4. Challenges and opportunities

The sustainable development and commercialisation of biofuel industry depends on several factors including government policy, target and mandates, and issues related to energy security, environment, social and economic impacts [21,39,40]. The challenges and opportunities relevant to the development of biofuels in South Africa are discussed in the following Sections 4.1 to 4.5.

4.1. Biofuel strategy

Despite having biofuels strategy in place since 2007, delays in its implementation due to political inaction and food security issues [31] is hindering the development of biofuels industry in South Africa. The strategy has been heavily criticized by maize farmers for excluding maize as ethanol feedstock. The exclusion will remain at least until the initial stage (5 year pilot) of biofuel development; however, the strategy acknowledged that the country has to conduct research on developing other crop varieties and second generation technologies to increase the nation's biofuel production levels.

4.1.1. Feedstock

Feedstock expansion and its choice are important in biofuel development as feedstock may be varied to reflect different climate, soil types and water demand. South Africa is a water-stressed country [17,41] with agriculture consuming about 60% of

the available resources for irrigation [17]. Diverting the existing allocation to produce new crops for biofuels can have significant impact on water scarcity. In drier regions, crops which do not rely on irrigation can be promoted instead of crops requiring large quantities of water. Dryland crops, such as soybeans, maize and jatropha are conservative water users [17,42]. African countries like Angola and Lesotho are promoting jatropha due to its suitability in semi-arid areas [22,42,43]. South Africa, however, excluded jatropha due to its invasive behaviour as reported by studies conducted in parts of Australia [42].

Maize is a major staple crop and a source of animal feed in Africa. The domestic consumption of maize has been increasing in recent years (Fig. 2), hence the strategy excluded it as ethanol feedstock to address possible food security and price hike issues. However, South Africa has a potential to produce maize in surplus amount from dedicated land [31,44]. The area under the maize has been decreasing over the years, whereas the production of maize has been increasing and the yield per unit area has almost doubled (Fig. 2). The surplus production of maize might provide a challenge to the South African government to consider using the surplus amount for biofuel production and alleviate economic burdens from the producers. Maize is also an export crop and its export has been steadily increasing (Fig. 2). A study is necessary to examine the sustainability impacts of using maize for energy production compared to exporting it.

A study by Department of Energy identified grain sorghum as a potential commercial ethanol feedstock, which may result in a major boost of grain sorghum output. Sorghum used to be produced extensively in the past, but production declined as the local market demand for sorghum decreased. Sorghum is resistant to drought and suited to be cultivated in large parts of South Africa, which makes it an attractive crop [46]. Sorghum yields the same amount of ethanol per bushel as maize and with development of improved ethanol processing units, sorghum may play crucial role in ethanol production. Besides these crops, South Africa can benefit from its abundant plant biomass to develop cellulosic ethanol. In South Africa, about 17.3 million tonnes of agricultural and forestry residues, and 8.7 million tonnes of invasive species are available each year [47]. However, the strategy is mainly focused on biofuel production from first generation feedstock.

4.1.2. By-products

The proposed biofuel blending mandates require processing large amount of feedstock which will produce large amount of

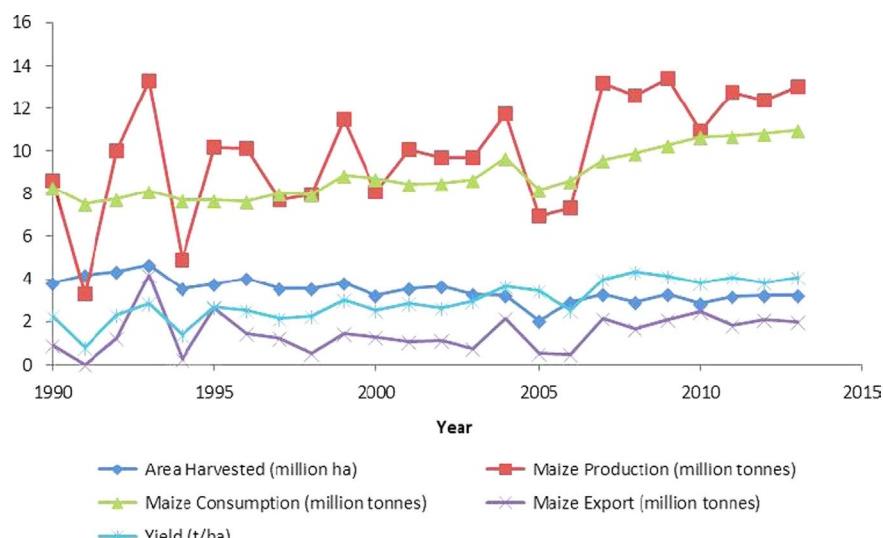


Fig. 2. Area coverage, production, consumption, exports and yield of maize in South Africa [45].

by-products. Crop residue, also called sugarcane bagasse, is a major by-product produced during the production of sugarcane ethanol. Bagasse can either be used directly as a solid biofuel to generate heat and electricity or it can be used as a feedstock for the production of cellulosic ethanol and other bio-based materials. Waste products produced during ethanol production can be used as soil amendments. The by-products of biodiesel are grain meal and glycerine. Grain meal can be used as animal feed and fertilizer, whereas glycerine can be used in pharmaceuticals and cosmetics.

The excessive availability of by-products can also raise the concern of oversupply, which may decrease the value of existing by-products. For instance, an increasing production of biodiesel in the world could oversupply glycerine and saturate its market which will eventually slump the price of glycerine [48]. The analysis for South Africa, however, showed that biofuel production of up to 4.5% will not oversupply the by-products [17]. Also, development of additional markets for alternative uses of these by-products are being explored worldwide, for instance research has found that glycerine from biodiesel can be used to replace fossil-based glycerine in livestock rations [49]. The South African biofuels strategy lacks planning on proper management of such large amount of by-products. A policy on the proper management of by-products with a consultation of relevant stakeholders is required to mitigate economic consequences on the off take of the by-products.

4.1.3. Technology and investment

The production technology and associated cost is determined by the type of feedstock used for biofuel production [50]. For instance, ethanol production from sugarcane involves processing sugarcane and fermenting lower quality sugar using yeast and nutrients; and cellulosic ethanol requires additional pre-treatment and enzymatic hydrolysis processes. Biodiesel production from oilseed requires oil extraction and transesterification reaction; and biodiesel from waste vegetable oil requires pre-treatment before conducting transesterification reaction. Compared to acid and alkali based, enzyme based transesterification reaction uses less alcohol and much lower temperature [51,52] saving energy, cost and CO₂ emissions but it involves cost of enzymes [52].

South Africa is well abreast of the production technology of the first generation biofuels, which is mature and well established [17]. New and advanced technologies for second generation biofuels is still being researched and at various stages of development around the world, including South Africa [26]. South Africa has a rich history in research and development of cellulosic biomass conversion technologies which began in the late 1970s when Council for Industrial and Scientific Research (CISR) began funding a research programme to develop a technically and commercially viable process to convert bagasse into ethanol [47].

Despite ongoing research and development to optimise feedstock and processing technologies being conducted at various universities and research institutes, the country is still being challenged with the considerable amount of investment and infrastructures required for sufficient supply and efficient conversion of feedstock into quality biofuels [21]. In order to obtain sufficient feedstock supply from targeted small scale farmers, South Africa needs more effort on farming units and knowledge, production efficiency and infrastructure, and general support structures of small scale farming. The current yield and production rate of WVO biodiesel in South Africa can be improved by some technological modifications, such as use of ultrasonic reactors [33].

The optimum biodiesel plant size in South Africa ranges between 13.5 million and 27.0 million litres per year and capital investment cost for these plants will range between 15.6 and 20.6 million USD (110 to 145 million ZAR) for biodiesel plant using

locally produced grains and between 6.4 and 7.1 million USD (45 to 50 million ZAR) for biodiesel plant using imported crude oil [48]. According to an initial economic modelling of biofuels using 2010 data, a sugar based ethanol plant in South Africa was estimated to be about 25% more expensive than sorghum based ethanol plant of the same size [46]. The study reported that the selling price and the cost of feedstock are the most sensitive variables for ethanol. Whereas soya meal price, sunflower seed price and the selling price were found to be the most sensitive variable for biodiesel. Due to the dynamics of market price, the models are required to be updated periodically to reflect the market. A comprehensive cost estimates on the productivity and return on investment at each step is essential to determine the feasibility of biofuel industry [53]. A feasibility study has indicated that biodiesel production from soybeans is viable in South Africa generating commercial returns without a need to provide subsidies [35].

4.2. Food versus fuel debate

Biofuel development has been blamed for increased food prices and reduced food to feed hungry mouths worldwide [40]. Critics continued to blame biofuels for the spike in food prices between 2005–2008 and 2010–2011 [54–56]. Biofuel expansion was blamed for 30% increase in grain price from 2000 to 2007 [57]. During 2008, the world experienced sudden increase in world food prices causing domestic prices of staple foods to increase by over 50% in some countries, for which the growth of biofuel industry was partially blamed [54,55]. However, recent studies found no direct correlation between the increased biofuel production and increasing food prices [58,59]. The maize prices hardly moved during the first period of increase in US ethanol production, and oilseed prices dropped when EU increased biodiesel use. On the other hand, prices spiked while ethanol use was slowing down in US and biodiesel was stabilizing in EU. Higher oil prices, expanding global demand of agricultural commodities, speculation in commodity markets and lax monetary policy were cited as the leading cause of increased price of food commodities worldwide [58,59]. The issues raised by different stakeholders on the impacts of biofuel on food security are one of the major concerns making South African government hesitant to approve commercial biofuel projects to date.

South Africa is a net exporter of food, especially sugar and maize, and has enough land to accommodate agricultural production for both food and fuel [31]. The 2% biofuel penetration level recommended in the Biofuels Industrial Strategy will require about 1.4% of arable land and about 14% of arable land was estimated to be underutilised [17]. Hence, the target can be achieved without jeopardising food security by targeting new and additional land. However, a key challenge lies in maximising agricultural productivity so that surplus production is available for biofuels without affecting the availability and pricing of food. This requires rigorous research efforts to increase agricultural productivity of especially first generation feedstock so that surplus production is available for biofuels [54].

4.2.1. Soybean production in South Africa

Soybeans in South Africa tend to have less controversy regarding food versus fuel debate because South Africa has enough land to accommodate agricultural production for both food and fuel with no shortage of cooking and edible oil [32,60]. Soybean is regarded as one of the main future energy crops in South Africa due to advances in locally adapted genetically modified varieties and high level of mechanization in soybean production. The area under soybean and its production have been increasing sharply over a decade (Fig. 3). This upward trend of soybean production in

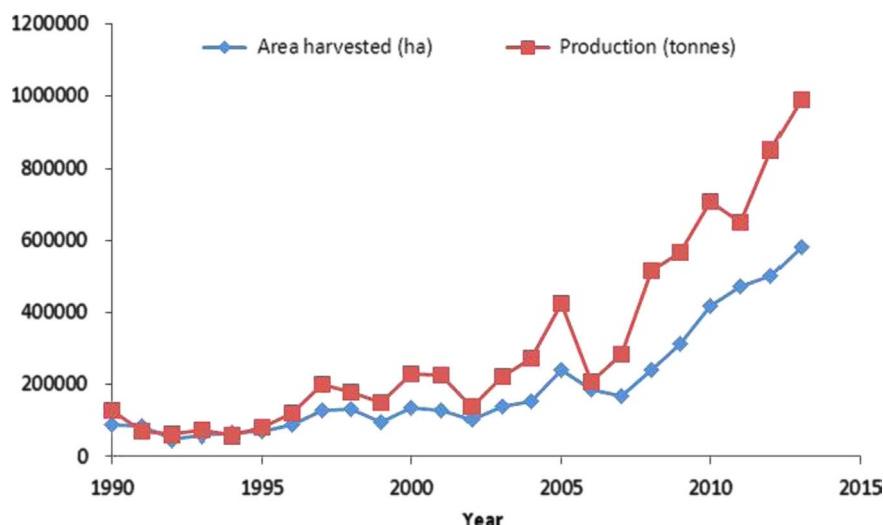


Fig. 3. Area coverage and production of soybean in South Africa [45].

Table 4
Sugarcane production and consumption in South Africa..

Items	2011/2012	2012/2013	2013/2014
Area harvested (1000 ha) ^a	271	274	310
Yield (t/ha) ^a	62.1	63.1	66.7
Sugarcane production (million tonnes) ^a	16.8	17.3	20.7
Ethanol from total sugarcane (litres) ^b	1.24	1.28	1.53
Sugar production (million tonnes) ^a	1.83	1.95	2.37
Sugar/sugarcane ratio	0.109	0.113	0.114
Sugar consumption (million tonnes) ^a	1.69	1.73	1.73
Surplus sugar (million tonnes)	1.43	2.27	6.10
Surplus sugarcane (million tonnes)	1.31	2.00	5.34
Ethanol from surplus sugarcane (million litres) ^b	97	148	394

^a Data obtained from [63].

^b Ethanol productivity used is 19.5 gallon per tonne of sugarcane [64].

South Africa is expected to continue in future with the increase in crushing capacity and growing demand for soy meal. South African Bureau for Food and Agricultural Policy (BFAP) projects 605 000 ha of soybeans could be planted producing about 1.62 million tonnes of soybeans by 2020. BFAP predicts an increase in the average soybean yield from 1.7 t/ha to 2.7 t/ha by 2020 [61].

A study by the United Nations in 2003 estimated that 1.4 billion litres of biodiesel could be produced in South Africa with the use of 2.3 million ha of land, without having an adverse impact on food supplies [62]. It was reported that even half of this projected amount could supply about 17% of current road and rail use of petroleum diesel in the country. It was estimated that about 280 million litres of biodiesel is needed to be produced in order to supply enough biodiesel to create a 5% blend (B5) for the entire nation.

4.2.2. South African sugar industry

South African sugar industry has been consistently producing and exporting surplus sugar and hence poses less risk in the food versus fuel debate. A surplus of about 5.3 million tonnes of sugarcane is estimated for 2013, which translates to about 394 million litres of ethanol (Table 4). Table 4 also shows the increasing trend of sugarcane surpluses and associated ethanol potential. Molasses, a by-product of sugar industry, contains about 60% of fermentable sugar and can be used to produce ethanol. Sugarcane

fibre, a residue left after sweet juice extraction, contains carbohydrates which can be used to produce ethanol which does not impact on food production. In addition to continued research and development of suitable alternative feedstock for first generation biofuels, estimation of the production potential of second generation biofuel requires advanced infrastructure and further research.

4.3. Environmental and land use change impacts

Biofuel production removes CO₂ from the atmosphere and thus reduces GHG emissions relative to fossil fuels which take carbon from the ground and emits it as CO₂. According to a study conducted by the South African government, about 30% and 50% reduction in GHG emissions can be achieved from ethanol and biodiesel, respectively [46]. The estimate was based on the environmental modelling of reference biofuel plants using data for the year 2010. The capacities of reference plants were 158 000 and 113 000 m³ per year for ethanol and biodiesel, respectively. However, the estimate does not mention any inclusion of emissions due to land use change (LUC).

4.3.1. Land use change impacts

The environmental benefits of biodiesel production are currently under a strong debate due to the influence of including net carbon flows associated with land use change (LUC). The potential impact of LUC on life cycle emission may be positive or negative. Biofuel production on previously sparsely vegetated and highly disturbed lands using reduced tillage and better crop management can result in a net gain in soil carbon. But if biofuels replace natural ecosystems, such as forest, wetlands, and grasslands, the effect will be mostly negative [65,66]. The effect of such direct LUC is well studied and default values are available [65], but the methods for measuring indirect LUC are still premature [67]. Indirect LUC is a displacement effect that accounts for diverting existing food and feed croplands into biofuels, which may result in clearing more forests or grasslands elsewhere to replace crops for feed and food [67].

While studies in the past blamed emissions due to LUC for a net increase in GHG emissions [66,68,69], recent studies including LUC emissions found biofuels to reduce GHG emissions compared to petroleum fuels and comply with lifecycle GHG threshold established by U.S. Energy Independence and Security Act (EISA) of 2007 [12,70,71]. The improvement in environmental performance

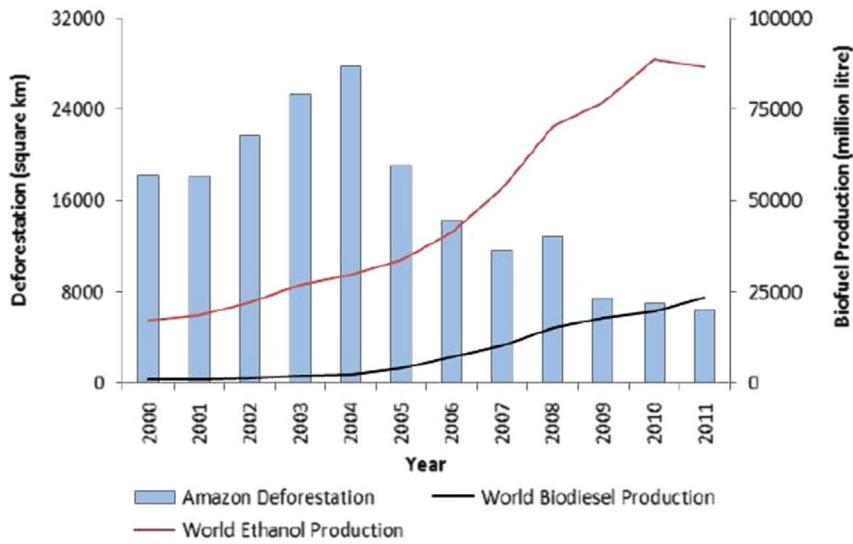


Fig. 4. World biofuel production and Amazon deforestation [1,73].

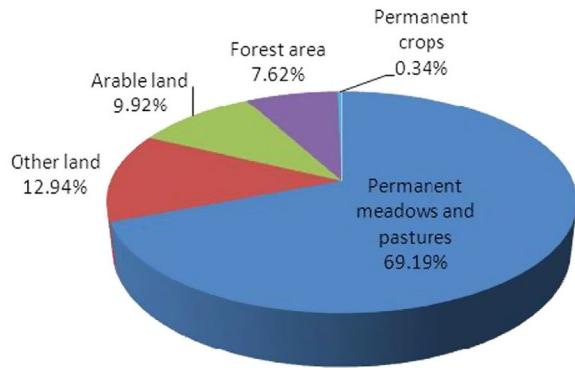


Fig. 5. National land cover of South Africa in 2011 [74].

of soybean biodiesel in the United States was attributed mainly to consistently increasing soybean yield from same or decreasing cropland [71]. Likewise, in contrast to the studies blaming biofuel feedstock expansion to deforestation [72], the statistics from Brazil's National Institute of Space Research (INPE) suggests the opposite. The INPE statistics shows that Amazon deforestation has fallen by 83% from 2004 to 2012, while biofuel industries in the world took off since 2004 (Fig. 4).

4.3.2. Land use pattern of South Africa

South Africa covers a land area of 121.3 million ha, of which over 96 million ha (about 80%) is used for agriculture and subsistence livelihood [74]. Only 13% of agricultural area has potential for crop production and the remainder is used for grazing. Some 1.6 million ha are under irrigation and produce a significant proportion of the nation's total agricultural output. Forestry and other land accounted for remaining 20% of the land (Fig. 5).

Over a decade, the transformed areas associated with other land have increased by 12.6% from 13.94 million ha in 2000 to 15.69 million ha in 2011, whereas areas under arable land and permanent crops have decreased by 12.3% from 14.19 million ha in 2000 to 12.45 million ha in 2011 [74]. The land use change over a decade is mainly attributed by increase in other land use types which include urban land. In the other words, the total food production in South Africa over last few decades has increased significantly mainly through improved productivity regardless of

decreasing cultivation land. In addition, there is a good deal of degraded land that could be improved for agriculture.

The demand for land to produce food, fibre and timber will continue to grow and the land requirement for biofuels development will have to be balanced within the emerging bio-economy of the country [21]. Considering the early phase of biofuel development in South Africa, comprehensive research and studies on the potential impacts of LUC on the environment are critical to develop appropriate strategies and refine biofuel policies.

4.4. Social and economic implications

In addition to the impacts of biofuel production on land use changes, biofuel development may lead to many important social and economic impacts in the country from health and safety to human rights to income and livelihood. The production of biofuel production generally occurs in rural areas with opportunities for agriculture, so developing biofuels is considered to provide energy and employment to rural people [22].

4.4.1. Social implications

Loss of land tenure and displacement of customary livelihoods resulting from large scale land transfers to biofuel investors is one of the most profound negative impacts of biofuel feedstock expansion [22,42,72]. Low farm wages, illegal workers from neighbouring countries, crime against commercial farmers and child labour are notable social issues of biofuel expansion in South Africa [32]. The government must take the measures to fully recognize and protect the rights of the tribal communities who are threatened by the expansion of biofuel development [75].

The preparation and implementation of guidelines for land reform and land tenure, healthy working environment, adequate work load and pay, protocols for monitoring and rewarding compliance might be a great challenge for the South African government. In addition, most of the social impact indicators are not easily accessible and quantifiable compared to energy and environmental impacts of biofuel feedstock expansion. An initial assessment conducted on social impacts of biofuel development suggested that South African biodiesel feedstock practices generally comply with the acceptable standards for human rights, working conditions, health and safety, and socio-economic aspects [32].

4.4.2. Economic implications

Creation of additional employment opportunities is considered as one of major benefits of the establishment of biofuel industry in the community. A feasibility study conducted by Biofuels Task Force indicated that biofuel industry will create about 39 850 jobs in South Africa, of which 86% will be in the agriculture sector [15]. An initial estimate showed that about 8400 and 20 000 additional jobs will be created from grain sorghum ethanol and soybean biodiesel plants, respectively [46]. If South Africa substitutes 15% of petrol demand by ethanol and replaces diesel with biodiesel, then a total of 350 000 direct jobs will be created [14]. Regular income flows from biofuel industry has been credited as a key benefit over agriculturally based livelihoods. Brazil stands top for providing quality employment with good wages and improved livelihood conditions [72].

The oil price has a significant influence on the economic performance of any country and especially for oil importing countries, the price of oil has impact on the trade balance. Oil has to be paid for in dollars and the Rand-Dollar exchange rate influence the import as well as domestic price of oil. According to the International Monetary Fund (IMF), the value of oil imports in South Africa has increased by four fold from 3.4 billion USD in 2000 to 14.1 billion USD in 2011 [76]. Since biofuels trade off fossil fuel, biofuel development has the potential to save considerable amount of foreign exchange. Between 1976 and 2004, Brazil saved an estimated amount of 50.2 billion euro on oil imports through its bio-ethanol programme [77]. The production cost of sugarcane ethanol in Brazil was estimated to be around 0.18 USD per litre compared to 0.46 USD per litre for maize ethanol production in the United States [78]. The production cost of soy biodiesel in U.S. was estimated to be 0.87 USD per litre. The competitive cost of biofuels when compared with conventional fuels is however driven by subsidized farming and tax incentives for producers and blenders.

The economics of biofuel production depends on the scale of the project because the unit costs for small scale projects are

higher than the large scale projects for the same crop. The processing cost per litre in small scale plants was found to be 75% higher than that in large scale plants [79]. The economics of biofuel production also varies with feedstock processing and the region where the biofuel plant is based. The production of feedstock accounts for the highest share of biofuel production costing up to 75% of the total cost of production. The lower labour costs, production technology and transportation cost in Brazil [79] are major reasons which contributed to the lower production costs of bioethanol (17–62%) compared to the US and Europe. Biofuel industry and community can also earn revenue from good management, proper marketing and export [16] of by-products, such as using or selling sugarcane residue for energy, oil meals as animal feed and fertilizer, and glycerine as chemical feedstock for pharmaceuticals, cosmetics, etc. Furthermore, developing biofuel plant in the vicinity of feedstock production area with co-located processing facilities (e.g. oil crushing mill and conversion facilities for biodiesel production) saves transportation cost and brings benefits directly to local communities [22].

4.5. Impact assessment studies

Despite being produced from renewable biomass resources, biofuel production uses variety of non-renewable resources over its life cycle, such as synthetic fertilizers to improve yields, fossil fuels for powering farm equipment and transportation vehicles, and energy uses in biofuel processing plants [71]. There has been some criticism that biofuels may not reduce fossil energy use and GHG emissions [80,81].

The energy and environmental impacts of biofuel production depends on feedstock and biofuel type. For instance, soybean requires less fertilizer and converting soybean oil to biodiesel requires far less energy than converting maize to ethanol [82]. Likewise, biodiesel produced from WVO will lower both raw material cost [83] and CO₂ compared to biodiesel produced from virgin oil [84,85]. A study of

Table 5
LCA Results for various biofuel production.

Biofuel	Feedstock	Energy ratio ^a	GHG emission ^b	Country	References
Ethanol	Corn	2.3		USA	[89]
		1.61	48–59%	USA	[86]
	Sugarcane	4.32	19–48%	USA	[90]
		8.3–10.2	46–62%	USA	[90]
				Brazil	[91]
			61%	Brazil	[92]
	Sugar beet	5.4	77%	Sweden	[93]
		1.3		Netherlands	[94]
		2.64	69–84%	Sweden	[93]
	Sorghum		32–52%	USA	[95]
Biodiesel	Crop residue (Cellulosic)	4.77–6.01	77–115%	USA	[90]
	Soybean	3.2	78%	USA	[7]
		5.54		USA	[18]
			62%	China	[96]
			81%	USA	[71]
	Canola		41–51%	Australia	[97]
		3.93	90%	Canada	[98]
	Sunflower	4.5		Greece	[99]
	Rapeseed	3.0	66%	EU	[100]
			34%	EU	[101]
Jatropha		3.77	42–74%	Sweden	[93]
		1.4–8.0	40–107%	India	[103]
			80%	China	[96]
			82%	China	[96]
Microalgae				USA	[104]
	WVO	7.8	84%	EU	[102]

^a Biofuel yield per unit of energy for every unit of fossil energy consumed over its life-cycle.

^b Emission reduction compared to that of petroleum counterparts.

maize ethanol biorefinery in United States reported that maize farming accounted for about 50% of total GHG emission, of which N₂O emission accounted for half of it [86].

Life cycle assessment (LCA) is used to quantify and compare energy and environmental flows associated both with biofuels and fossil fuels [18,87]. Many biofuel LCAs have been conducted following International Organization for Standardization (ISO) standards confirming the renewability and lower pollution levels of biofuels compared to that of petroleum counterparts (Table 5). The wide range of results reported for different biofuel LCA are mainly due to differences in the selection of feedstock, biofuel production technology, system boundary and co-product allocation methods [88].

Delay in the implementation of Biofuels Industrial Strategy in South Africa provides an opportunity to consider the potential impacts and benefits of biofuel industry, and the selection of feedstock and technologies [21]. At present, South Africa lacks comprehensive assessment of impacts of developing biofuels on energy security, environment and economics of the country. LCA will be useful in exploring and selecting feedstock and technologies best suited to South African biofuel industry, which can further assist policymakers in supporting biofuel products that results in the least burden to environment, economy and society of the country.

5. Conclusion and recommendations

Biofuels have the potential to extend and diversify South Africa's energy supply which helps reduce South Africa's foreign dependence on oil and carbon footprint. Over the years, South Africa has established several biofuel policies and mandates aiming to promote the production and use of biomass based fuels, attract investment into rural agricultural development, and create additional employment. Despite many policy statements and plans, there is still no large scale commercial biofuel industry in the country. However, few manufacturing sites have been identified and licenced for large scale commercial biofuel production.

Though the justification of biofuel targets to reduce GHG emissions and enhance energy security is attractive, the consequences of biofuel development on local and global land use change, food insecurity and socio-economic impacts are complex. Since the initial growth of biofuel industry in South Africa will depend on first generation technologies, biofuel development in the country needs rigorous research efforts to increase agricultural productivity so that surplus production is available for biofuel production. Both sugarcane and soybean are being consistently produced in surplus amount, which can be used for biofuel production without posing much risk on food security. However, further research will be needed to establish the production potential, viability and impacts of the promising alternative biofuel feedstock. Since cellulosic biomass does not impact on food production, research needs to be conducted on suitability of cellulosic biomass as a feedstock for biofuel production in South Africa. The production cost of feedstock accounts for the highest share of total biofuel production, hence the selection of feedstock appropriate to the region plays a vital role in the biofuel policy. Furthermore, the feedstock selection can contribute to the rural employment creation from agricultural production.

Studies and reports have shown that South Africa has the capability and resources for biofuel development. The country has about 14% of arable land underutilized. This can be used for biofuel development without jeopardising food security and land use change issues. In addition to this, South Africa has a good deal of degraded land that can be improved for agriculture. However, a considerable amount of investment required for continued supply of appropriate feedstock, improved infrastructure and efficient biomass

conversion technologies will be a big challenge for the South African government. In addition, advanced research on technological expansion will be essential to allow for increased possibilities of alternative feedstock and efficient conversion processes.

The South African government requires that a minimum of 25% of the feedstock supply for recommended biofuel blending must come from small scale farmers. However, South Africa lacks farming units and knowledge, production efficiency and infrastructure, and general support structures of small scale farming. In addition to biofuel blending rules and production targets set by the South African government, environmental and socio-economic criteria should be enunciated in biofuel policies with provisions for strong implementation through mandatory use of strategic impact assessments of biofuel expansion on environment, economics and society.

It is sensible to measure the benefits and consequences of biofuel production before the establishment of biofuel industries in the country. The life cycle approach should be used over the value chain of biofuels to measure and compare energy and environmental performances of biofuels and fossil fuels. Globally, several studies have been conducted on biofuel development showing both positive and negative impacts on the environment, land use change, biodiversity, economics and society. Such studies provide comparative results over the petroleum counterparts and can help policy makers to support a product that results in the least burden to the environment and society. However, South Africa lacks such comprehensive studies which can be critical in identifying feedstock and technologies best suited for the South African environment, economics and society. Such studies provide vital information to policy makers with the broader impacts of biofuel development, and hence help the government to revise and implement biofuel policy suitable for successful development of biofuels in the Republic of South Africa.

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References

- [1] US EIA. International energy statistics. Energy Information Administration, United States. Available from (<http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm>); 2013 [accessed 6 September 2013].
- [2] Blanco M, Adenauer M, Shrestha S, Becker A. Methodology to assess EU biofuel policies: the CAPRI approach. Joint Research Centre, Institute for Prospective Technological Studies. European Commission; 2013.
- [3] IEA. Technology roadmap: biofuels for transport. Organisation for Economic Cooperation and Development, International Energy Agency; 2011.
- [4] von Malitz GP, Brent A. Assessing the biofuel options for Southern Africa. In: CSIR (Council for Scientific and Industrial Research), Science real and relevant: second CSIR biennial conference. Pretoria, South Africa, 17–18 November, 2008. Pretoria: CSIR; 2008.
- [5] Anderson JE, DiCicco DM, Ginder JM, Kramer U, Leone TH, Raney-Pablo HE, et al. High octane number ethanol-gasoline blends: quantifying the potential benefits in the United States. Fuel 2012;97:585–94.
- [6] Foong TM, Morganti KJ, Brear MJ, da Silva G, Yang Y, Dryer FL. The octane numbers of ethanol blended with gasoline and its surrogates. Fuel 2014;115:727–39.
- [7] Sheehan J, Camobreco V, Duffield J, Graboski M, Shapouri H. Life cycle inventory of biodiesel and petroleum diesel for use in an urban bus. Golden, Colorado: National Renewable Energy Laboratory; 1998 NREL/SR-580-24089.
- [8] Lane J. Biofuels mandates around the world 2014. Biofuels Dig 2014.
- [9] Gilbert A, Pinzon L. Colombia biofuels annual: blend mandates maintain status quo as a biofuel policy vision remains unclear. Global agricultural information network, United States Department of Agriculture 2013.
- [10] Diop D, Blanco M, Flammini A, Schlaifer M, Kropiwnicka MA, Markhof MM. Assessing the impact of biofuels production on developing countries from the point of view of policy coherence for development. European Commission; 2013.

- [11] Esterhuizen D. Sugar annual—Republic of South Africa. Global Agricultural Information Network, United States Department of Agriculture. Available from (http://gain.fas.usda.gov/Recent_GAIN_Publications/Sugar_Annual_Pretoria_South_Africa - Republic_of_4-17-2013.pdf); 2013 [accessed 10 September 2013].
- [12] US EPA. EPA finalizes regulations for the National Renewable Fuel Standard program for 2010 and beyond. Environmental Protection Agency, EPA-420-F-10-007, Washington, D.C., United States. Available from (<http://www.epa.gov/oataq/renewablefuels/420f10007.pdf>); 2010 [accessed 10 September 2013].
- [13] US EPA. EPA proposes 2014 renewable fuel standards, 2015 biomass-based diesel volume. Environmental Protection Agency, EPA-420-F-13-048, Washington, D.C., United States; 2013.
- [14] Silalertruksa T, Gheewala SH, Hünecke K, Fritzsche UR. Biofuels and employment effects: implications for socioeconomic development in Thailand. *Biomass Bioenergy* 2012;46:409–18.
- [15] APEC. A study of employment opportunities from biofuel production in APEC economies. Asia-Pacific Economic Cooperation, APEC #210-RE-01.9; 2010.
- [16] Avinash A, Subramaniam D, Murugesan A. Bio-diesel—a global scenario. *Renewable Sustainable Energy Rev* 2014;29:517–27.
- [17] SA DoME. Biofuels industrial strategy of the Republic of South Africa. Department of Minerals and Energy, South Africa. Available from (http://www.energy.gov.za/files/esources/petroleum/biofuels_indus_strat.pdf%2829.pdf); 2007 [accessed 6 September 2013].
- [18] Pradhan A, Shrestha DS, McAloon A, Yee W, Haas M, Duffield JA. Energy life-cycle assessment of soybean biodiesel revisited. *Trans ASABE* 2011;54(3):1031–9.
- [19] Duku MH, Gu S, Hagan EB. A comprehensive review of biomass resources and biofuels potential in Ghana. *Renewable Sustainable Energy Rev* 2011;15:404–15.
- [20] Figiel S, Hamulczuk M. The effects of increase in production of biofuels on world agricultural prices and food security. *Eur Sci J* 2013;10–7 (1 (December special edition)).
- [21] Blanchard R, Richardson DM, O'Farrell PJ, von Maltitz GP. Biofuels and biodiversity in South Africa. *S Afr J Sci* 2011;107(5/6) (Art. #186).
- [22] Amigun B, Musango JK, Stafford W. Biofuels and sustainability in Africa. *Renewable Sustainable Energy Rev* 2011;15(2):1360–72.
- [23] Gasparatos A, Lee LY, von Maltitz GP, Mathai MV, de Oliveira JAP, Willis KJ. Biofuels in Africa—impacts on ecosystem services, biodiversity and human well-being. United Nations University—Institute of Advanced Studies; 2012.
- [24] Tatsidjodoung P, Dabat MH, Blin J. Insights into biofuel development in Burkina Faso: potential and strategies for sustainable energy policies. *Renewable Sustainable Energy Rev* 2012;16:5319–30.
- [25] Mohammed YS, Mustafa MW, Bashir N. Status of renewable energy consumption and developmental challenges in Sub-Saharan Africa. *Renewable Sustainable Energy Rev* 2013;27:453–63.
- [26] von Maltitz G, Haywood L, Mapako M, Brent A. Analysis of opportunities for biofuel production in Sub-Saharan Africa. Bogor, Indonesia: Center for International Forestry Research (CIFOR); 2009.
- [27] BP BP. Statistical review of world energy 2013. London, UK: BP p.l.c.; 2013.
- [28] Feygin M, Satkin R. The oil reserves-to-production ratio and its proper interpretation. *Nat Resour Res* 2004;13(1):57–60.
- [29] SA DoE. Statistics: national aggregated fuel sales volume 2012. Department of Energy, South Africa; 2014. Available from (http://www.energy.gov.za/files/energyStats_frame.html); 2012 [accessed 17 March 2014].
- [30] SA DoME. White paper on renewable energy. Department of Minerals and Energy, South Africa. Available from (http://www.energy.gov.za/files/esources/petroleum/white_paper_renewable_energy.pdf); 2003 [accessed 6 September 2013].
- [31] Esterhuizen D. South Africa: biofuels annual. Global agricultural information network. United States Department of Agriculture; 2009.
- [32] Mbohwa C, Myaka N. Social life cycle assessment of biodiesel in South Africa: an initial assessment. In: Proceedings of the ninth international conference on ecobalance, towards and beyond 2020; 2010.
- [33] Mbohwa C, Mudiwakure A. The status of used vegetable oil (UVO)_biodiesel production in South Africa. In: Proceedings of the world congress on engineering 2013, vol. I, WCE 2013, July 3–5, 2013, London, UK; 2013.
- [34] SA DoE. Update on the biofuels industrial strategy. Department of Energy, South Africa. Available from (<http://www.innovationeasterncape.co.za/download/presentation18.pdf>); 2012 [accessed 6 September 2013].
- [35] NBTT. National biofuels study: an investigation into the feasibility of establishing a biofuels industry in the Republic of South Africa. National Biofuels Task Team, South Africa. Available from (http://www.cityenergy.org.za/files/transport/resources/biofuels/bio_feasible_study.pdf); 2006 [accessed 6 September 2013].
- [36] Brent A, Sigamoney R, von Blottnitz H, Hietkamp S. Life cycle inventories to assess value chains in the South African biofuels industry. *J Energy South Afr* 2010;21(4):15–25.
- [37] Funke T, Strauss PG, Meyer F. Modelling the impacts of the industrial biofuels strategy on the South African agricultural and biofuel subsectors. *Agrekon* 2009;48(3):223–44.
- [38] SA DoE. Mandatory blending of biofuels with petrol and diesel to be effective from the 01 October 2015. Media Statement, Department of Energy, South Africa. Available from (<http://www.energy.gov.za/files/media/pr/2013/MediaStatement-Mandatory-Blending-of-Biofuels-with-Petrol-and-Diesel.pdf>); 2013 [accessed 1 October 2013].
- [39] Amigun B, Sigamoney R, von Blottnitz. Commercialisation of biofuel industry in Africa: a review. *Renewable Sustainable Energy Rev* 2008;12:690–711.
- [40] Ulmanen JH, Verbong GPJ, Raven RPJM. Biofuel developments in Sweden and the Netherlands protection and socio-technical change in a long-term perspective. *Renewable Sustainable Energy Rev* 2009;13:1406–17.
- [41] Haw M, Hughes A. Clean energy and development for South Africa: background data. Energy Research Centre, University of Cape Town 2007.
- [42] Gasparatos A, Lee LY, von Maltitz GP, Mathai MV, de Oliveira JAP, Willis KJ. Biofuels in Africa: impacts on ecosystem services, biodiversity and human well-being. United Nations University—Institute of Advanced Studies. Available from (http://www.ias.unu.edu/resource_centre/Biofuels_in_Africa.pdf); 2012 [accessed 16 September 2013].
- [43] Achtem WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, et al. Jatropha bio-diesel production and use. *Biomass Bioenergy* 2008;32(12):1063–84.
- [44] Visagie E, Prasad G. South Africa: biodiesel and solar water heaters. Renewable energy technologies for poverty alleviation, Energy Research Centre. South Africa: University of Cape Town; 2006.
- [45] Indexmundi. Agricultural production by country: South Africa. Available from (<http://www.indexmundi.com/agriculture/?country=za&graph=production>); 2013 [accessed 178 March 2014].
- [46] SA DoE. Biofuels pricing and manufacturing economics. Department of Energy, South Africa. Available from (<http://www.energy.gov.za/files/esources/renewables/BiofuelsPricingAndManufacturingEconomics.pdf>); 2013 [accessed 6 September 2013].
- [47] Lynd LR, von Blottnitz H, Tait B, de Boer J, Pretorius IS, Rumbold K, et al. Converting plant biomass to fuels and commodity chemicals in South Africa: a third chapter? *S Afr J Sci*, 99; 2003; 499–507.
- [48] Nolte M. Commercial biodiesel production in South Africa: a preliminary economic feasibility study. Department of Process Engineering, University of Stellenbosch; 2007.
- [49] Popp J, Lakner Z, Rákos MH, Fári. The effect of bioenergy expansion: food, energy, and environments. *Renewable Sustainable Energy Rev* 2014;32:559–78.
- [50] Issariyakul T, Dalai AK. Biodiesel from vegetable oils. *Renewable Sustainable Energy Rev* 2014;31:446–71.
- [51] Shah S, Sharma S, Gupta MN. Enzymatic transesterification for biodiesel production. *Indian J Biochem Biophys* 2003;40:392–9.
- [52] Gog A, Roman M, Tos M, Paizs C, Irimie D. Biodiesel production using enzymatic transesterification. *Renewable Energy* 2012;39:10–6.
- [53] Puri M, Abraham RE, Barrow CJ. Biofuel production: prospects, challenges and feedstock in Australia. *Renewable Sustainable Energy Rev* 2012;16:6022–31.
- [54] OFID. Biofuels and food security: implications of an accelerated biofuels production. The Opec Fund for International Development, Vienna, Austria; 2009.
- [55] Thompson PB. The agricultural ethics of biofuels: the food vs. fuel debate. *Agriculture* 2012;2:339–58.
- [56] Tenenbaum DJ. Food vs. fuel: diversion of crops could cause more hunger. *Environ Health Perspect* 2008;116:A254–7.
- [57] Rosegrant MW. Biofuels and grain prices: impacts and policy responses. International Food Policy Research Institute, Washington DC; 2008.
- [58] Baffes J, Haniotti T. Placing the 2006–08 commodity price boom into perspective. Policy Research Working Paper 5371, The World Bank. Available from (http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2010/07/21/000158349_20100721110120/Rendered/PDF/WPS5371.pdf); 2010 [accessed 10 September 2013].
- [59] Urbanchuk JM. The renewable fuel standard and consumer food prices. ABF Economics, Agriculture and Biofuels Consulting. Available from (http://ethanolrfa.3cdn.net/281d77a62939896ba8_8nm6bevpj.pdf); 2013 [accessed 16 September 2013].
- [60] Sparks GD, Ortmann GF, Lagrange L. An economic evaluation of soybean based biodiesel production on commercial farms in the soybean producing regions of KwaZulu-Natal: some preliminary results. In: Joint third AAAE and 48th AEASA Conference, Cape Town, South Africa. Available from (http://ageconsearch.umn.edu/bitstream/95980/2/89_Soybean_biofuels_in_KZN_South_Africa.pdf); 2010 [accessed 6 September 2013].
- [61] Esterhuizen D. Soybean production in South Africa could reach 1.62 million tonnes by 2020. Global Agricultural Information Network, United States Department of Agriculture. Available from (<http://www.thebioenergysite.com/articles/812/soybean-production-in-south-africa>); 2010 [accessed 16 September 2013].
- [62] Pahl G. Biodiesel: growing a new energy economy. 2nd ed. Chelsea Green Publishing; 2008.
- [63] Esterhuizen D. Sugar semi-annual—Republic of South Africa. Global Agricultural Information Network. United States Department of Agriculture; 2013.
- [64] Shapouri H, Salassi M, Fairbanks JN. The economic feasibility of ethanol production from sugar in the United States. Office of Energy Policy and New Uses, Office of the Chief Economist, United States Department of Agriculture and Louisiana State University; 2006.
- [65] Gnansounou E, Panichelli L, Dauriat A, Villegas JD. Accounting for indirect land use changes in GHG balances of biofuels. EPFL-ENAC-LASEN, LAUSANNE. Available from (http://www.bioenergywiki.net/images/b/b0/2008_LASEN-EPFL_-_Accounting_for_IUC_in_biofuels_production-final_version.pdf); 2008 [accessed 16 September 2013].
- [66] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. *Sci Exp* 2008;2.

- [67] Fehrenbach H, Fritzsche UR, Giegrich J. Greenhouse gas balances for biomass: issues for further discussion. German Federal Environment Agency, Brussels. Available from <http://www.oeko.de/service/bio/dateien/en/ghg_balance_bioenergy.pdf>; 2008 [accessed 16 September 2013].
- [68] Delucchi M. Lifecycle analyses of biofuels. Draft report, Institute of Transportation Studies, University of California; 2006 (Davis, UCD-ITS-RR-06-08).
- [69] Searchinger T, Heimlich R. Estimating greenhouse gas emissions from soy-based U.S. biodiesel when factoring in emissions from land use change. Life cycle carbon footprints of biofuels workshop. Report no. 49099, January 2008, Miami Beach, Florida; 2008.
- [70] US EPA. Renewable Fuel Standard Program (RFS2) regulatory impact analysis. Environmental Protection Agency, EPA-420-R-10-006. Washington, D.C., United States. Available from <<http://www.epa.gov/otaq/renewablefuels/420r10006.pdf>>; 2010 [accessed 10 September 2013].
- [71] Pradhan A, Shrestha DS, Van Gerpen J, McAlloon A, Yee W, Haas M, et al. Reassessment of life cycle greenhouse gas emissions for soybean biodiesel. Trans ASABE 2012;55(6):2257–64.
- [72] German L, Schoneveld GC, Paheco P. Local social and environmental impacts of biofuels: global comparative assessment and implications for governance. Ecol Soc 2011;16(4):29.
- [73] Butler RA. Deforestation in the Amazon. Available from <<http://www.monabay.com/brazil.html>>; 2012 [accessed 20 September 2013].
- [74] FAOSTAT. Resources. Food and Agricultural Organization Statistics. Available from <<http://faostat.fao.org/site/377/default.aspx#ancor>>; 2013 [accessed 18 September 2013].
- [75] Manik Y, Leahy J, Halog A. Social life cycle assessment of palm oil biodiesel: a case study in Jambi Province of Indonesia. Int J Life Cycle Assess 2013;18:1386–92.
- [76] International Monetary Fund. World economic outlook database. Available from <<http://www.imf.org/external/ns/cs.aspx?id=28>>; 2013 [accessed 16 September 2013].
- [77] Worldwatch Institute. Biofuels for transport: global potential and implications for sustainable energy and agriculture. London, Sterling: VA: Earthscan; 2007.
- [78] BBI Biofuels Canada. Biofuels costs, technologies and economics in APEC economies. APEC # 210-RE-01.21, APEC Project EWG 16/2009. Available from <http://www.biofuels.apec.org/pdfs/ewg_2010_biofuel-production-cost.pdf>; 2010 [accessed 10 September 2013].
- [79] Clancy J. Biofuels and rural poverty. NY 10017, USA. 1st ed. Routledge; 2013.
- [80] Pimentel D. Biomass utilization, limits of. Encyclopedia of Physical Science and Technology. Academic Press, San Diego 2001;2:159–71.
- [81] Pimentel D, Patzek TW. Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. Nat Resour Res 2005;14(1):65–76.
- [82] Searchinger T, Heimlich R, Houghton RA, Dong F, Elbehri A, Fabiosa J, et al. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. Science 2008;319(5867):1238–40.
- [83] Zhang Y, Dubé MA, McLean DD, Kates M. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. Bioresour Technol 2003;89:1–16.
- [84] Chhetri AB, Watts KC, Islam MR. Waste cooking oil as an alternate feedstock for biodiesel production. Energies 2008;1:3–18.
- [85] Refaat AA. Different techniques for the production of biodiesel from waste vegetable oil. Int J Environ Sci Technol 2010;7(1):183–213.
- [86] Liska AJ, Haishun SY, Bremer VR, Klopfenstein TJ, Walters DT, Erickson GE, et al. Improvements in life cycle energy efficiency and greenhouse gas emissions of corn-ethanol. J Ind Ecol 2009;13(1):58–74.
- [87] Sobrino FH, Moroy CR, Pérez JLH. Biofuels and fossil fuels: life cycle analysis (LCA) optimisation through productive resources maximisation. Renewable Sustainable Energy Rev 2011;15:2621–8.
- [88] Pradhan A, Shrestha DS, Van Gerpen J, Duffield J. The energy balance of soybean oil biodiesel production: a review of past studies. Trans ASABE 2008;51(1):185–94.
- [89] Shapouri H, Gallagher PW, Nefstead W, Schwartz R, Noe S, Conway R. 2008 Energy balance for the corn ethanol industry. USDA Agricultural Economic Report no. 846. Available at: <http://www.usda.gov/oce/reports/energy/2008Ethanol_June_final.pdf>; 2010 [accessed 18 March 2014].
- [90] Wang M, Han J, Dunn JB, Cai H, Elgowainy A. Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. Environ Res Lett 2012;7:4.
- [91] Macedo IC, MRLV Leal, daSilva JEAR. Assessment of greenhouse gas emissions in the production of and use of fuel ethanol in Brazil. Government of the State of São Paulo; 2004.
- [92] RFA. RFS2 final rule lifecycle GHG analysis “By The Numbers”. Renewable Fuels Association. Available at: <http://ethanolrfa.3cdn.net/a05aec0d7576eb4606_fjm6ivcli.pdf>; 2010 [accessed 18 March 2014].
- [93] Börjesson P, Tufvesson L, Lantz M. Life cycle assessment of biofuels in Sweden. Department of Technology and Society, LUND University. Available at: <http://www.miljo.lth.se/svenska/intern/publikationer_intern/pdf-filer/Report%2070%20-%20LCA%20of%20Biofuels%20%281%29.pdf>; 2010 [accessed 18 March 2014].
- [94] Langeveld H, van de Ven G, de Vries S, van den Brink L, de Visser C. Ethanol from sugar beet in The Netherlands: energy production and efficiency. In: Eighth European IFSA Symposium, 6–10 July 2008, France. Available at: <http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2008/2008_WS5_09_Langeveld.pdf>; 2008 [accessed 18 March 2014].
- [95] US EPA. EPA issues supplemental determination for renewable fuels produced under the final RFS2 program from grain sorghum. Environmental Protection Agency, EPA-420-F-12-078. Washington, D.C., United States. Available at: <<http://www.epa.gov/otaq/fuels/renewablefuels/documents/420f12078.pdf>>; 2012 [accessed 18 March 2014].
- [96] Hou J, Zhang P, Yuan X, Zheng Y. Life cycle assessment of biodiesel from soybean, jatropha and microalgae in China conditions. Renewable Sustainable Energy Rev 2011;15:5081–91.
- [97] Beer T, Grant T, Williams D, Watson H. Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles. Atmos Environ 2002;36:753–63.
- [98] (S&T)² Consultants Inc. Lifecycle analysis canola biodiesel. Canola Council of Canada. Available at: <http://canola.ab.ca/uploads/biodiesel/Canola_Lifecycle_Analysis.pdf>; 2010 [accessed 18 March 2014].
- [99] Kallivroussis L, Natsis A, Papadakis G. The energy balance of sunflower production for biodiesel in Greece. Biosyst Eng 2002;81(3):347–54.
- [100] CIEME. Análisis de Ciclo de Vida de Combustibles alternativos para el Transporte, Fase II Comparative LCA of Biodiesel and Diesel, Energy and Climate Change; 2006.p. 96–108.
- [101] Scharmer K, Gosse G. Energy balance, ecological impact and economics of vegetable oil methyl ester production in Europe as substitute for fossil diesels. Study alterner 4.1030/E/94-002-1, EU; 1995.
- [102] JRC. Summary of energy and GHG balance of individual pathways. JEC—Joint Research Centre-EUCAR-CONCAWE collaboration, WTT Appendix 2 (Version 4). Available at: <http://iet.jrc.ec.europa.eu/about-jec/sites/iet.jrc.ec.europa.eu.about-jec/files/documents/report_2013/wtt_appendix_2_v4_july_2013_final.pdf>; 2013 [accessed 18 March 2014].
- [103] Kumar S, Singh J, Nanoti SM, Garg MO. A comprehensive life cycle assessment (LCA) of jatropha biodiesel production in India. Bioresour Technol 2012;110:723–9.
- [104] Hoover S. Energy balance of a grassroots biodiesel production facility. School of Engineering Science, Division of Science and Engineering, Murdoch University. Available at: <<http://www.biofuels.coop/education/resources/energy-balance>>; 2005 [accessed 18 March 2014].